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## Restoration of an 18<sup>th</sup> century frame: 3D modelling, printing and matching color of decorative flowers elements

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**Abstract:** This paper describes the application of 3D digital technology to support the rebuild of lost decorative elements of an historical frame. The frame belongs to an 18th century painting depicting the portrait of D. José, Prince of Brazil, displayed at the National Palace of Queluz, Portugal. The application of digital technologies has been planned from the very beginning in order to avoid the traditional use of silicone in the reproduction of missing elements. The photogrammetric 3D acquisition, a non-contact methodology, has been used to reduce the manipulation and hence prevent further degradation of the artistic object. Following the 3D modelling operation, new decorative elements were made using an additive printing technology. In the final phase of the work, the post-printing treatment was carried out, in which aqueous products were used. 3D modelling, in addition to facilitate the restoration treatment of the historic frame, can also be useful in the creation of a digital collection of decorative frame elements, i.e. a virtual database.

**Keywords:** digital technologies, photogrammetry, restoration, frame, 3D printing, post-printing treatment, matching colour

### Restauración de un marco del siglo XVIII: modelado 3D, impresión y acierto de colores de elementos florales decorativos

**Resumen:** Este artículo describe la aplicación de tecnologías digitales 3D para apoyar la reconstrucción de elementos decorativos faltantes en un marco histórico. El marco pertenece a una pintura del siglo XVIII, que representa el retrato de D. José, Príncipe de Brasil, expuesto en el Palacio Nacional de Queluz, Portugal. Se planificó, desde el principio, la aplicación de tecnologías digitales de forma a evitar el uso tradicional de siliconas en la reproducción de elementos faltantes. La adquisición fotogramétrica 3D, una metodología sin contacto, se ha utilizado para reducir la manipulación y, por tanto, evitar una mayor degradación del objeto artístico. Tras la operación de modelado 3D, se realizaron nuevos elementos decorativos utilizando tecnología de impresión aditiva. En la fase final del trabajo se realizó el tratamiento de post-impresión, en el que se utilizaron productos acuosos. El modelado 3D, además de facilitar los tratamientos de restauración en el marco histórico, también puede considerarse útil en la creación de una colección digital de elementos decorativos de marcos, es decir, una base de datos virtual.

**Palabras clave:** tecnologías digitales, fotogrametría, restauración, marco, impresión 3D, tratamiento de postimpresión, acierto de color

### Restauro de uma moldura do século XVIII: modelação 3D, impressão e acerto de cor de elementos florais decorativos

**Resumo:** Este artigo, descreve a aplicação de tecnologias digitais 3D, como base para a reconstrução de elementos decorativos em falta, numa moldura histórica. A moldura pertence uma pintura do século XVIII, que representa o retrato de D. José, Príncipe do Brasil, exposto no Palácio Nacional de Queluz, Portugal. A aplicação das tecnologias digitais foi planeada desde o início, para evitar o uso tradicional de silicones na reprodução dos elementos inexistentes. A aquisição fotogramétrica 3D, uma metodologia sem contato, foi utilizada de forma a reduzir a manipulação, evitando uma maior degradação do objeto artístico. Após a operação de modelação 3D, os novos elementos decorativos foram feitos usando uma tecnologia de impressão aditiva. Na fase final do trabalho, foi realizado o tratamento de pós-impresão no qual foram empregues produtos aquosos. A modelação 3D, além de facilitar a intervenção de restauro na moldura histórica, também pode ser considerada útil na criação de uma coleção digital de elementos decorativos de molduras, ou seja, um banco de dados virtual.

**Palavras-chave:** tecnologias digitais, fotogrametria, restauro, moldura, impressão 3D, tratamento de pós-impresão, acerto de cor

## Introduction

The acquisition of a 3-dimensional (3D) digital model has been established as a common practice in many Cultural Heritage applications (Levouy *et al.* 2000; Bernardini 2002; Fontana 2002; Callieri *et al.* 2011; Remondino 2009; Falkingham 2012; Niquet & Mas-Barbera, 2018). Such computer aided technologies are being used for diagnostic and non-invasive documentation in conservation and restoration projects (Callieri *et al.* 2004; Arpace *et al.* 2013; Callieri *et al.* 2015; Bailão *et al.* 2017; Alquini *et al.* 2018), for analytical and web interactive visualization purposes (Pereira 2016), and in many other areas. In the field of heritage conservation, 3D digitizing techniques has also been useful to create digital archives of 3D models, to produce high fidelity physical replicas of art-works, to the remote fruition of cultural heritage, to digital restoration and to the monitoring of cultural heritage (Pieraccini *et al.* 2001).

The accurate 3D surface model can be obtained using a 3D scanner or a photogrammetric technique. That digitization pipeline can be performed with active or passive sensors - range-based modelling (RBM) or image-based modelling (IBM), respectively. Several authors explain the main differences between the 3D scanning and photogrammetry technique (Böhle & Marbs 2004, Kadobayashi *et al.* 2004, Remondino *et al.* 2013), and for the conservation and restoration purposes the biggest advantages of photogrammetry over 3D scanning is the portability, the low-cost and, not less important, the quality of textures obtained in the 3D model.

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as the “art, science, and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena” (Cooper & Robson 1996).

The photogrammetry can facilitate the recording of an accurate detailed 3D information of an object at any visible scale. It is considered a very useful technique for the processing of image data and is often applied in 3D documentation of Cultural Heritage. According to many authors, e.g. Wolf (1983) or Remondino (2011), the acquisition of the images can be done using satellite, aerial or terrestrial sensors, that are then processed following the photogrammetric pipeline. This process is semi-automatic and is generally based on sensor calibration and image orientation. After the resultant image is produced, it is possible to apply various operations such as surface measurement, feature extraction, and, if necessary, the orthophoto generation as an important document to support the graphical mapping of pathologies.

This work is based on the use of a close-range photogrammetric images. The close range is referred

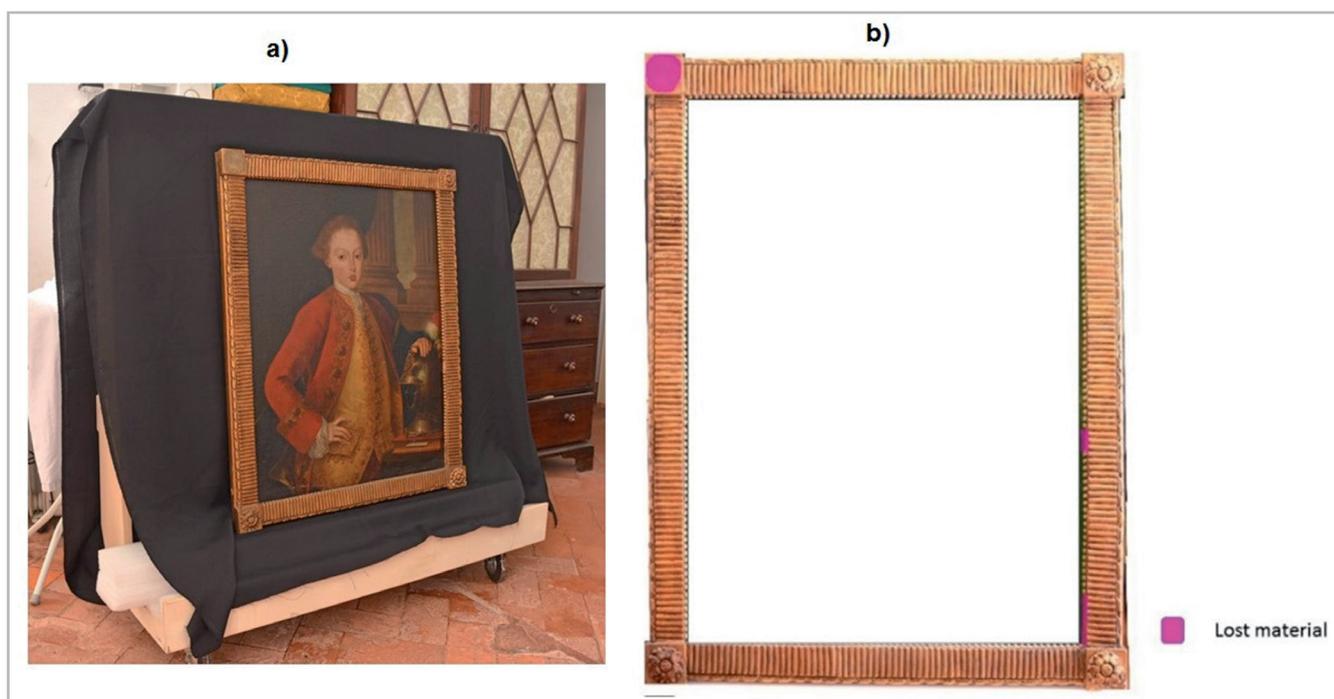
to photographs where an object-to-camera distance is limited, with some considering 300 meters as a maximum distance (Karara 1985). Following the data acquisition using the photographic camera, where studio conditions are preferable, the following step is the 3D model preparation. Examples of the applications and comparative studies using open-source software are well known (Kersten & Lindstaedt 2012; Remondino *et al.* 2012; Schoning & Heidemann 2012; Koutsoudis *et al.* 2013; Schöning & Heidemann 2015; Siotto *et al.* 2015; Rahaman & Champion 2019). The commercial software applied to this end are, e.g., *Agisoft Metashape*<sup>®</sup>, *3D Zephyr*<sup>®</sup>, *Reality Capture*<sup>®</sup> and many others. In this project it was used the *Agisoft Metashape*<sup>®</sup>, a low-cost commercial 3D reconstruction software from *Agisoft LLC* (Russia). *Metashape*<sup>®</sup> automatically builds precise textured 3D, an advantage really useful for the final matching colour of the decorative frame elements.

The use of replicas made with 3D printing technologies for museums is not new. There are several studies that explore this subject (Allard *et al.* 2005, Balletti *et al.* 2017), from its production to the interaction that museum visitors have with this objects (Neumüller 2014; Franco *et al.* 2015; Wilson 2018). However, in the context of conservation and restoration, the reconstruction of volumetric elements is an unwell developed theme (Scopigno *et al.* 2014; Santos Gómez, 2016).

The paper is organized as follows: the case study is first described, followed by the specification of the 3D model acquisition (photogrammetry and image processing). The subsequent section gives a detailed description of the reconstruction process of the missing ornaments using a 3D printing technique. The final step is about the post-processing in 3D printing. This step refers to processes or techniques used to further enhance the object, is a finishing touch to treat and refine parts that come out of a 3D printer, in this case, using as reference the preserved elements of the frame. Finally, some concluding remarks are given.

## Case study

This case-study is focused on the conservation and restoration process, particularly the reconstruction of missing decorative elements, of an 18<sup>th</sup> century frame made for the Portrait of D. José, Prince of Brazil. The painting is attributed to António Amaral and the frame is of an anonymous artist/carver. The frame is made of pine, joined together with animal glue and gilded with non-original bronze powder paints, a probable mixture of copper and zinc. The first observation of the frame revealed extensive damages [Figure 1]: longitudinal cracks, the ornaments were loose and some of the decorative elements had been lost. Moreover, there was some mechanical damage and some glued pieces (from past interventions). Some elements were also missing: a flower on the top left corner and some of the pearl shape decorations. In addition, the bronze powder paints were also tarnished.



**Figure 1.**-a) Painting placed on a wood vertical structure that was used for transport; b) The frame with the indication of the missing elements

The standard procedure for replacing missing ornaments is to create a replica by taking a cast of a preserved element. However, in this case, due to the fragility of the preparation layer and the metallic surface of the frame, it was decided that the missing pieces should be done in a way to reduce manipulation, thus preventing further damage. After some research, it was decided that the 3D print could be an option. The project began in the Palace of Queluz, where dirt and other superficial deposits were removed. Animal glue was used to attach loose parts and to secure the original layers of preparation.

### 3D Model acquisition

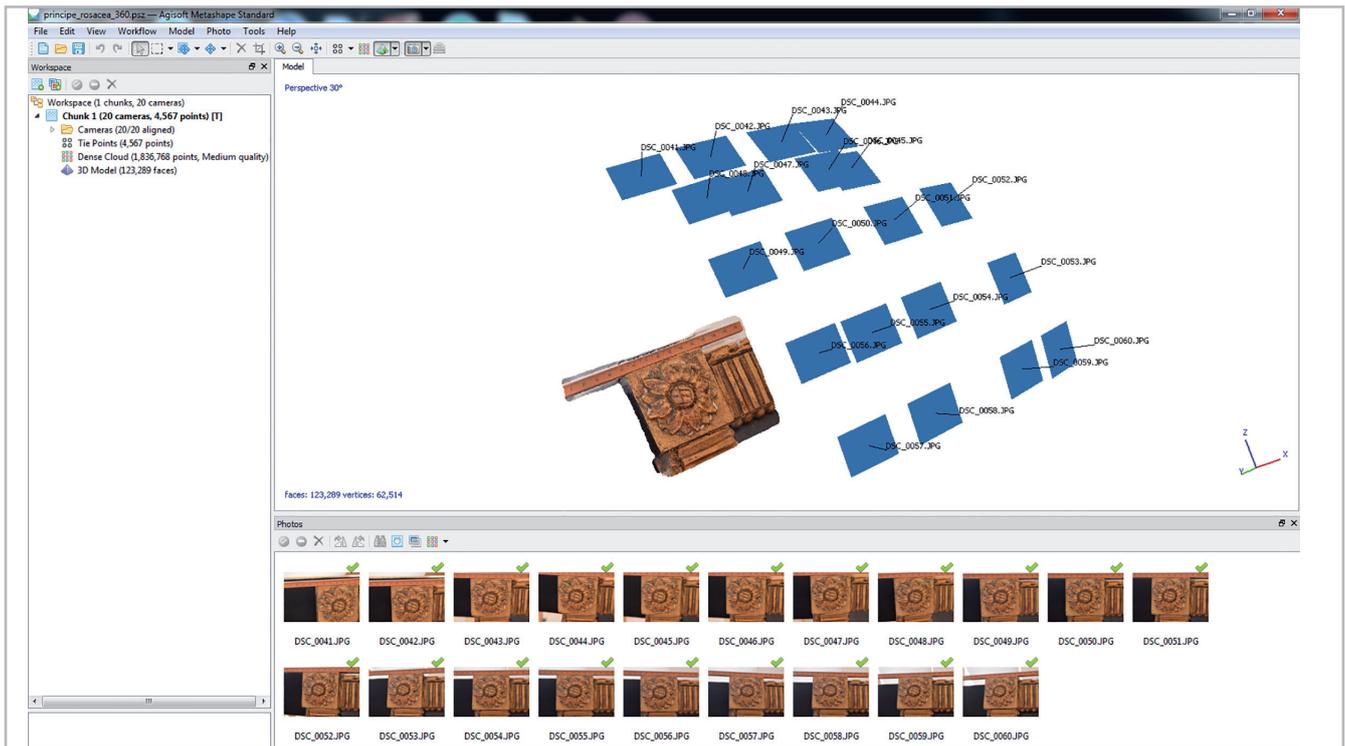
To achieve the 3D model of the missing ornaments two tasks were made: the photographic acquisition and the image-based modelling (structure-from-motion). The photos were acquired with a Nikon D3200® digital camera; its technical features include a 23.2 x 15.4 mm CMOS image sensor, an 18-55 mm optical AF-S and a Nikon Multi-CAM 1000 autofocus sensor module with TTL phase detection. The process of camera calibration was fully automatic. Because the geometry of the surface to model was relatively simple, a total of 20 photographs in mosaicking mode were taken of the upper right-side flower. The photographic conditions were: 100 ISO; f/8.0; 2.5s; focal length 55 mm; tripod and Nikon ML-L3 Wireless Remote.

In this section, it is important to note that some authors (Porter et al 2016), indicate that the photographic acquisition for photogrammetry (bundle restitution) should be, for example, every 10 degrees. However, based on the present experiment, the number of photographs

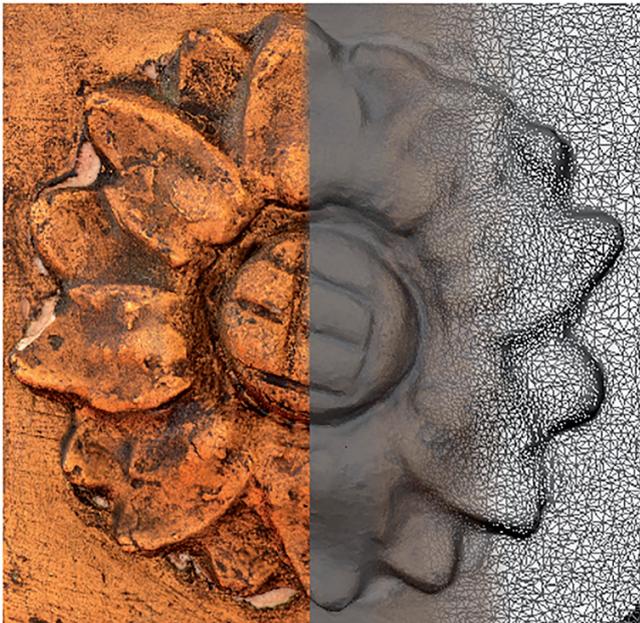
does not depend on a rule of angles, but on the type of surface geometry. It is important that all photography's have a significant image overlay (approx. 60%) and that each point on the surface is recorded by three images. For Grussenmeyer *et al.* (2002), the bundle acquisitions are made with this guideline: "The strategy of taking photos is that each point to be determined should be intersected by at least two rays of satisfactory intersection angle". So, as long as the photographic acquisition always has the entire object on the scene, it is sufficient to use 20 photographs in the photogrammetric processing to obtain the geometric model with good textures.

The photos were taken in a non-studio environment, composed of one wood vertical structure used to transport the painting. A piece of black fabric was used as a background, as suggested by Guidi *et al.* (2013), in order to have a good contrast between the colour of the object and the background. The choice of a black background avoids some topological errors in the mesh. The light source was a halogen lamp with a light temperature of 5500 K. Homogeneity of brightness, although essential, was difficult to obtain - if the light intensity varies, common points determined on a photo by photogrammetry software, will not be the same from one photo to another. The photos were taken in a symmetrical ornament, similar to the one that was missing. To reduce and mitigate the shining of the surface, a polarize filter was used (circ. Polarizer COKIN 58mm).

To create the 3D decorative flower of the frame, multiple overlapping photographs, in mosaicking mode (not rounded), with more than 60% of the object, were taken and then uploaded into the widely used photogrammetric



**Figure 2.-** Multiple overlapping photographs, with more than 60% between each capture, were taken and uploaded into the photogrammetric modelling software *Agisoft Metashape*®.



**Figure 3.-** The image illustrates three steps of the 3D model (from left to right): model with chromatic texture; model in solid mode (without texture); triangular wireframe (mesh).

modelling software *Agisoft Metashape*® [Figure 2]. The acquisition in mosaicking mode is better to adjust the depth of field and the focus in all regions of the flower. With this strategy, it is possible to acquire more sharp photos.

This software has been chosen due to its ability to generate highly detailed 3D models. According to its developers, this software performs photogrammetric processing of digital

images and generates 3D spatial data. After the upload is essential to do the alignment of the photos; the aim is to compare the pixels of the photographs, in order to find matches and estimate camera locations and 3D geometry from them. Here it is fundamental that the homogeneity of the light intensity does not change. Afterwards, the sparse point cloud is processed into a dense cloud in which each pixel will get its own X, Y, Z location in 3D space. This step is called Build Dense Cloud.

Next, is necessary to Build the Mesh. This step connects each set of three adjacent points into a triangular face, which combines perfectly to produce a continuous mesh over the surface of the model. Finally, the last step is the Build of Texture, when the original images are combined into a texture map, resulting in a photorealistic model of the original object. With this technique, highly detailed three-dimensional models are obtained [figure 3].

### Reconstruction of missing elements

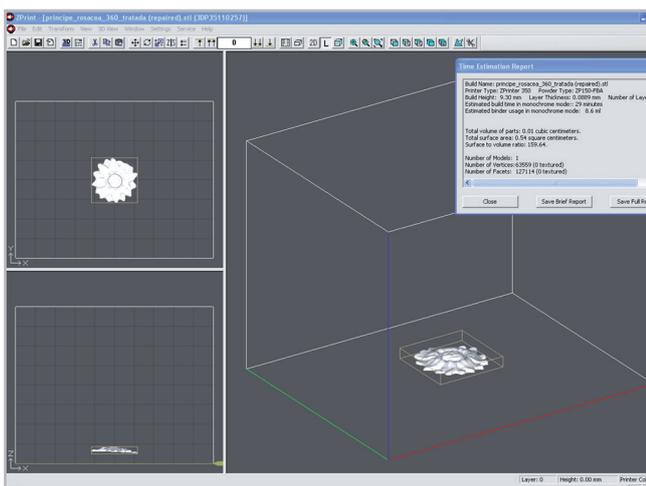
#### —File preparation

After producing the model in the photogrammetric software, it was exported in STL format to Meshmixer, a 3D modelling software to clean up the model and prepare it to the 3D printing. The STL format file uses triangles to reproduce the object surface geometry. This file only contains data about the geometry and it doesn't conserve other model attributes such as colour or texture (Ramos *et al.* 2017). For printing, the scale and volume calculation,

were processed with specific slicing software from the 3D printer used for the final result: ZPrinter 350® with ZPrint program from ZCorporation.

In order to determine inaccuracies of the 3D object mesh and also to correct proportions for its exact integration in the 18th century frame, it was 3D printed a test model in Fused Deposition Modelling (FDM) technology. The Fused Deposition Modelling was developed by Scott Crump in 1988. This process allows low cost model fabrication obtained by the extrusion of thermoplastic materials through a nozzle, adding layer by layer, until a 3D model geometry is complete (Ramos *et al.* 2017). The choice for this type of 3D printing as a testing tool, lies in its low cost and in the variety of materials available, which allows to study the shape and also to try out several types of finishes that can be used in the final object. A Prusa i3 Hephastos® printer and PLA (Polylactic Acid) were used for this verification.

With the model corrected and prepared for 3D printing the document was imported in STL format to ZPrint slicing software (version 7.12.14). In the ZPrint program, the object was then orientated and positioned on the different axes in the build plate and the dimensions were also confirmed. Since the parts to be printed had a flat surface, the objects were oriented on the Z axis and centred on X and Y as shown in Figure 4. In this software, it was also possible to estimate the time and material needed, and to select the 3D print quality - defined by layer height (0.0889 mm) - in order to achieve the best possible quality. After setting all the parameters it was time to start the 3D printing [Figure 4].



**Figure 4.-** Object orientation on the build plate and materials/ time estimation for the 3D printing (flower).

### 3D printing

The final model was printed in an Inkjet Powder Bed 3D Printing. The system of the printer is powder based or binder jetting (ASTM terminology). This printer was first

developed at the Massachusetts Institute of Technology in 1993 and in 1995, Z Corporation obtained an exclusive license (Grimm 2004). The object to be printed is built up from many thin cross sections of the 3D model. An inkjet print head moves across a bed of powder, selectively depositing a liquid binding material. A thin layer of powder is spread across the completed section and the process is repeated with each layer adhering to the last (Sclater 2001; Ramos 2017). When the model is complete, the unbound powder can be automatically or manually removed and can be reused. This process is called *de-powdering* [Figures 5 and 6]



**Figure 5.-** ZPrinter 350® used for the 3D print of the missing elements



**Figure 6.-** De-powdering of the newly-printed element through brushing, vacuum and compressed air.

After removing the remaining powder that has not been in contact with the binder, it was necessary to finish the 3D print process. For this purpose, two methods can be considered: spraying a solution of hot water and salt, or making an infiltration with cyanoacrylate, by dipping or drizzling. Since the second option is the most common and it gives a superior mechanical strength and durability to the printed part, and also because it is suggested by

the manufacturer (ZPrinter®, 2012), it was decided to finish the pieces with this process.

To post-processing the newly-printed parts by the dipping method, it was used ColorBond™ infiltrator and it was proceeded as follows:

- a) Placing of a wax paper near the container and pouring enough ColorBond™ into it to completely submerge the element;
- b) The element was gently submerged into the liquid until the air bubbles stopped and then removed from the container. The element started to get very warm due to the powder reaction with the infiltrator;
- c) Quickly and thoroughly wipe any excess liquid off the element with paper towels and placing it on the wax paper;
- d) While the object was cooling and drying it was moved around on the wax paper so it didn't glue to the paper.

In this process, the reaction between the infiltrator and the powder is a critical moment as it causes heating, which can lead to deformation of the object while being handled. Quick handle it's crucial to prevent any damage. Other precautions are necessary during the drying and cooling, in order to avoid cyanoacrylate accumulation into certain areas, or even the bonding between the paper and the printed part, which would require its subsequent rectification - the object should be moved around to clean areas on the wax paper. Finally, between 30 minutes to one hour, the newly-printed parts are totally dry and able to go to the finishing and painting stage, so they could be integrated into the 18th century frame accurately.

### Post-processing techniques

Cleaning the surface is an important phase since it eliminates dirt and oils, and improves the strength of the joints. In order to get a smoother surface, it was used sandpaper in the 3D printed objects.

The model was then tested on the frame to understand its proper position [figure 7]. Afterwards, three layers of primary gesso from *Royal Talens*®, with one day to dry between each application, were applied over the printed pieces. In the next phase, using a scalpel, the lines were enhanced in the gesso layers to evidence patterns similar to the remaining decorative ornaments.

When the gesso processing was completed, the surfaces were prepared with a layer of gouache paint, consisting of a mixture of yellow ochre (PY 43) and iridescent pigments or mica pigments [figure 8].



**Figure 7.-** The image on the left shows the 3D model next to an original and symmetrical decorative ornament; the image on the right register the moment when the 3D model was tested on the frame.



**Figure 8.-** Surface of the printed model after the application of yellow ochre and mica pigments.

Gouache was the selected material for the chromatic reintegration. Almost all pigments are suitable to use in gouache paint and the intention was to use iridescent pigments to achieve a "gold effect". Gouache paint comprises of a mixture of pigment and gum Arabic, and is distinguishable from watercolour because of its higher hiding power. Since gouache usually contains more fillers, the dry colour appears lighter than the wet colour, making the colour match a little more difficult than with a watercolour due this colour change, however, this is compensated by the opacity of the gouache (Bailão and Cardeira 2017).

Other selected materials were the mica pigments or iridescent pigments. These pigments are often used as an alternative to the use of metallic leaves and bronze powders when retouching losses of gilded objects. The mica powders are non-toxic and do not tarnish. When mixing mica with a binder that does not yellow in time, it is believed that the

conservator-restorer can create a surface coating that will retain its original appearance for many years (Bailão and Sustic 2013). Paraloid® B72 diluted in isopropyl alcohol (3%) was used for binding the mica pigments.

When the paint dried it was brushed with a microfiber textile to achieve a smooth and bright surface. After that, two layers of red oxide (PR 101) and burnt umber (PBr 7) gouache were added, both with small portions of mica pigments. These layers did not cover the surface totally. They were applied with a stencil brush - a brush with short bristles and with a small width. It was used in a straight up-and-down pouncing motion, rather than a long swoop side to side or up and down. Using this brush, it was possible to achieve distinctive colour spots over the 3D model, similar to the original. As said before, these mica pigments can be mixed with almost any medium without tarnishing or reacting in any way.

An essential task in the post-processing techniques is colour enhancement. This step refers to a treatment that enhances the colour of an object. While it is usually difficult for an untrained eye to detect, colour variations can greatly affect and determine the quality of the final work. To enhance the colour of the 3D printed flower, it was used a brush with a soft silicone rubber head, which is very useful for shaping contours and achieve shadows in the concavities. For that, it was applied burnt umber (PBr 7) gouache with some ultramarine blue (PB 27).

As protective layer and finishing varnish, Paraloid® B72 diluted in isopropyl alcohol (3%), was applied. Paraloid® is a copolymer of methyl methacrylate and ethyl methacrylate with high mechanical strength and removability. Is considered stable and durable in the long term. The resin



**Figure 8.-** After the 3D reconstruction and post-processing of the decorative element (flower).

film, after drying, is more matte when compared to natural resins or polycyclohexanones, due to its lower refraction index, around 1.487 (Rie 1987). This characteristic is suitable for this case-study. Also, the fact that the copolymer creates an uneven film on the surface that causes the incident light to be diffuse, helps to minimize the differences between original and non-original [Figure 9]

## Conclusion

The aim of this project was to apply and test innovative computer-based technologies, combining low-cost techniques on 3D representation and 3D printing, for the restoration of missing parts in cultural heritage preservation. The case-study was an 18<sup>th</sup> century frame and the main goal was to recreate the missing decorative elements, using existing similar elements.

Firstly, the 3D model was generated using photogrammetry techniques then, the models were printed in *Inkjet Powder Bed 3D Printing*®, that uses plaster as printing material. In this way it was possible to achieve a more realistic 3D model. Finally, 3D printing post-processing techniques were applied to achieve an object similar to the reference element. Cleaning and surface improvement were necessary before colour application. Gouache and iridescent pigments allowed to reach similarity. Colour enhancement was also important to give quality to the final object.

Digital technologies are transforming the way cultural heritage researchers and conservators-restorers work, by providing new ways to collaborate, record interventions, conserve and restore objects. With 3D modelling techniques and 3D printing technology, the Conservation and Restoration is faced with new challenges in this Digital Era.

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